Appendix F.
Determination of the Hydrologic Period for Model Application

Section 6.1.1 defined the hydrologic period for application of the suite of Chesapeake Bay models and reported that the 10-year period 1991–2000 was selected on the basis of a number of criteria. This appendix documents the analyses behind the selection of the hydrologic averaging period.

The hydrologic period for modeling purposes represents a typical or representative long-term hydrologic condition for the waterbody. The hydrologic period is used for expressing average annual loads from various sources. It is not to be confused with the critical period, which defines a period of high stress (see Sections 6.2.1 and 6.4.1 and Appendix G). It is important that the selected hydrologic period is representative of the long-term hydrology in each area of the Chesapeake Bay watershed so that no one area is modeled with a particularly high or low loading or an unrepresentative mix of point and nonpoint sources. The selection of a representative hydrologic averaging period ensures that the balance between point and nonpoint source loading and the balance between different geographic areas are appropriate.

Because of the long history of stream flow and water quality monitoring in the Chesapeake Bay watershed, the Chesapeake Bay Program partners were in the position of selecting a period for model application representative of typical hydrologic conditions from among the 21 contiguous model simulation years—1985 to 2005. The partners first selected 10 years as the appropriate number of years for the hydrologic period and then selected the best contiguous 10-year period.

Methods

Monitored stream/river flow was used exclusively as the indicator of hydrology. Three other criteria were investigated and evaluated by the Chesapeake Bay Program's Water Quality Goal Implementation Team but were not used.

1. Rainfall: Stream/river flow was judged to be a better overall indicator than rainfall as flow integrates the effects of evapotranspiration and snowpack effects of temperature. Flow is also more tractable to work with because the nine river input monitoring stations characterize flows and pollutant loads from 80 percent of the Chesapeake Bay watershed, whereas approximately 500 rainfall stations are across the entire Chesapeake Bay watershed.
2. Water quality: Observed water quality was considered as an ancillary criterion but was eventually rejected. Observed water quality is dependent, in part, on management actions taken throughout the Bay watershed. The Chesapeake Bay Program's Water Quality Goal Implementation Team decided that the criteria for selecting the hydrologic period should be independent of management actions.
3. Modeled loads: The EPA Chesapeake Bay Program Office performed an analysis of modeled loads to investigate the change in the fraction of load by major river basin and pollutant loading source sectors for different hydrologic averaging periods. This criterion was also rejected by the Water Quality Goal Implementation Team because it incorporated the effects from management actions and not just hydrology.

The objective of selecting a hydrologic period is to ensure that the period has flow statistics that were representative of the long-term flow statistics and that the representativeness held across different areas of the Bay watershed. Flow statistics for periods of different length and starting years were considered. To judge the overall representativeness, several statistics were calculated.

1. Mean flow anomaly: This statistic is the absolute value of the difference between the mean flow value for any given period and the long-term mean, divided by the long-term mean. If the mean flow value for a candidate period were equal to the long-term mean, the value of this indicator would be zero. If the mean flow value for a candidate period were either zero or twice the long-term mean, the value would be one.
2. Standard deviation anomaly: Similar to the mean anomaly, this statistic is the absolute value of the difference between the standard deviation of a candidate period and the long-term standard deviation divided by the long-term standard deviation.
3. Kolmogorov-Smirnov (K-S) test statistic: The K-S test is a common nonparametric method of comparing two distributions. The cumulative frequency distributions of two populations are plotted together, and the maximum distance between the two distributions on the probability axis is used at the test statistic, commonly known as D. From that test statistic, P values are generally calculated and hypothesis tests run. In the analyses for selecting the hydrologic period, a candidate period distribution is compared to a long-term distribution. For this work, the Water Quality Goal Implementation Team decided to use the D statistic. The D is monotonically related to the P value in this case because the number of observations was constant across analyses and the distribution of the D values was more suited to this work. The D statistic was calculated for the daily flow for an estimate of the agreement in short-term events and for the annual flow for an estimate of the agreement in inter-annual variability.

The nine river input stations compose the set of farthest-downstream, well-monitored flow stations on significant rivers flowing to the Chesapeake Bay, measuring river flow close to the point where the free-flowing river enters the Bay's tidally influenced waters. The analysis used a 30-year flow period that was common to all nine stations and also a long-term flow that used different flow period lengths for each major river basin (Table F-1). In both analyses, only years without missing data were used. At the time of this analysis, the last full year record of flow data was 2006, so the 30-year analysis used all data from 1977 to 2006.

Table F-1. The nine major Chesapeake Bay river flow gage stations used in the determination of the Chesapeake Bay TMDL hydrologic period

Gage ID	Flow gage station description	Full years in the 30-year record*	Full years in long-term record
1668000	Rappahannock River near Fredericksburg, VA	30	99
1646502	Potomac River (Adjusted) near Washington, DC	30	77
2037500	James River near Richmond, VA	30	72
1674500	Mattaponi River near Beulahville, VA	28	64
1673000	Pamunkey River near Hanover, VA	30	65
1491000	Choptank River near Greensboro, MD	30	60
1578310	Susquehanna River at Conowingo, MD	30	40
2041650	Appomattox River at Matoaca, VA	30	37
1594440	Patuxtent River near Bowie, MD	29	29

* The 30-year record is 1977-2006.

Selecting the Number of Years

Ten years was selected as an appropriate length of time as the following analysis showed that most of the 12 possible 10-year contiguous periods are statistically similar to the long-term flow record.

To reduce the dimensionality of the analysis, the Water Quality Goal Implementation Team recommended using a statistic that combined the mean and standard deviation of a given candidate period compared to the same statistics for the 30-year period. The combined statistic allows depiction of a single statistic rather than multiple statistics for easier interpretation. The combination statistic was simply the average of the mean flow anomaly and the standard deviation anomaly described above. The flow and standard deviation anomalies were calculated separately for each of the nine river stations and then averaged. Lower values of the combined statistic correspond to more representative periods.

Because the hydrologic period had to be within the Chesapeake Bay model simulation period of 1985–2005, only periods that fell within that 21-year window were considered. The combined statistic was calculated for each instance of each window length that occurred within the modeling period. For example, the statistic was calculated for two 20-year periods, 1985–2004 and 1986–2006 and for 16 6-year periods, 1985–1990, 1986–1991, ... 2000–2005. For each candidate hydrologic period length, the minimum, maximum, and average values of the combined statistic were tabulated and are plotted in Figure F-1.

Figure F-1 illustrates that when using 10 or more contiguous years, all possible candidate periods are score relatively well using the combined metric. With fewer than 10 years, there is a mix of periods that score well and periods that score poorly. A 10-year period was chosen by the Water Quality Goal Implementation Team as a robust choice for the length of the hydrologic period.

Selecting the Ten-Year Period

There are 12 possible 10-year contiguous periods from 1985 to 2005. Although the above analysis suggests that any of the periods might be acceptable, a more detailed analysis showed that some regional differences and overall statistical differences exist between the candidates. As with selecting the number of years, a combined statistic reduced the dimensionality to make the analysis more tractable. For the analysis, the Water Quality Goal Implementation Team agreed on developing a statistic that combined mean anomaly, standard deviation anomaly, and the D statistic for daily and annual flow. Those four statistics were normalized by the average value of each statistical type individually and then averaged so that the overall score for all 10-year periods centered around one. The averages were plotted separately for each of the nine major river basins.

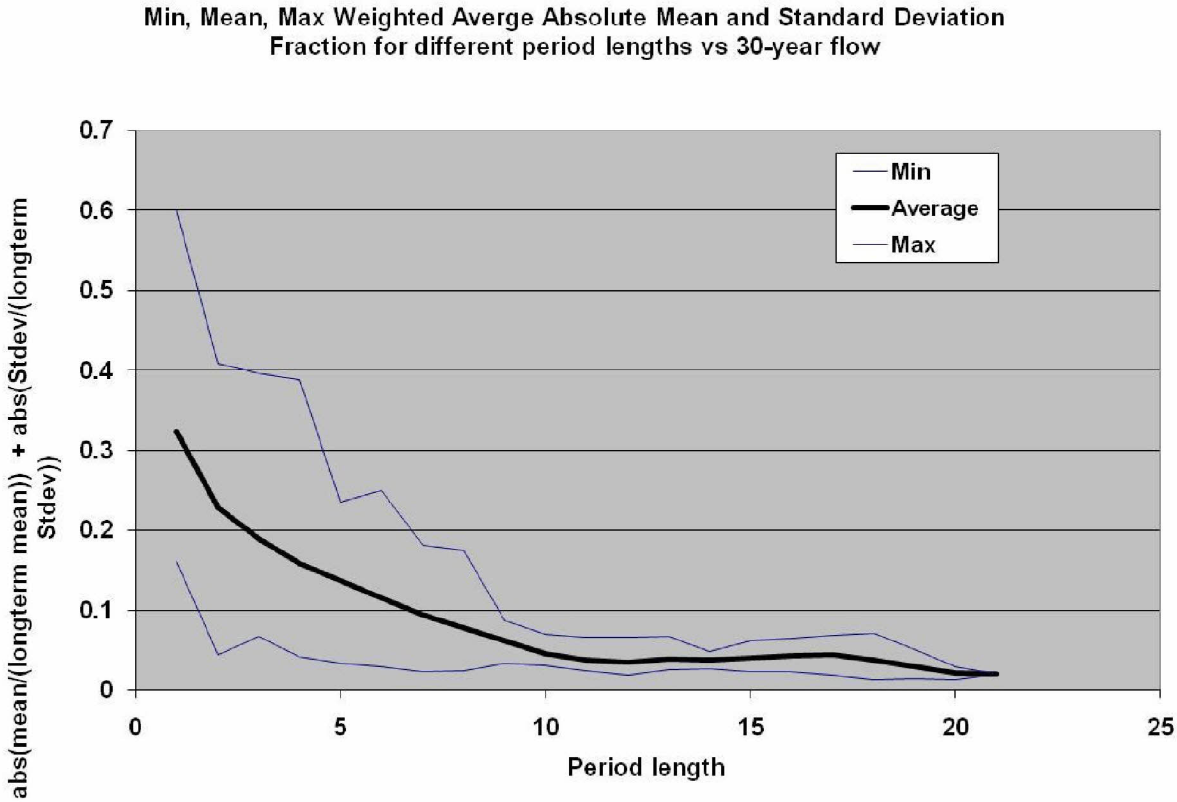
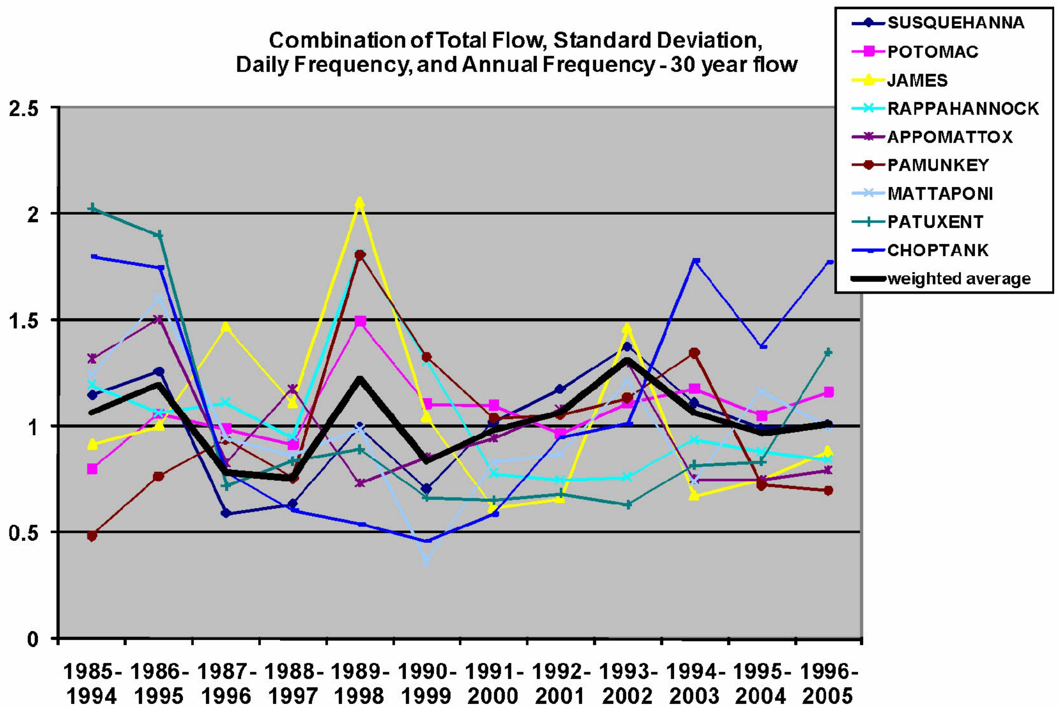


Figure F-1. Range of values of the combined flow statistic for different period lengths.

For example, the mean anomaly in the James River Basin for 1985–1994 was divided by the average mean anomaly of all twelve 10-year periods in the James River Basin. The standard deviation anomaly and D statistics for 1985–1994 were divided by the average of their counterparts for all twelve 10-year periods. The four values were averaged to get an overall score for 1985–1994 in the James River Basin. That process was repeated for each basin and for the flow-weighted average of all nine major river basins for each candidate period. Both the 30-year flow and the long-term flow were considered. The results are shown in Figure F-2.

In Figure F-2, the statistics are all compared to the average, so the average value is one. Lower values reflect better statistical fit to the long-term data set, so values below one are the better candidates for a representative hydrologic period. The thick black line in Figure F-2 is the flow-weighted average of the values for the individual major river basins and, therefore, the best overall indication of statistical fit.

Another consideration is the size of the spread around the flow-weighted average. A tighter distribution means that the good statistical fit holds across all major river basins and is not an unrepresentative hydrologic period for any major river basin. The candidate periods 1987–1996, 1988–1997, 1990–1999, and 1991–2000 are all better than average in terms of the statistical fit (Figure F-2). However, the first three candidate periods—1987–1996, 1988–1997, and 1990–1999—all have individual major river basins that are not good statistical fits. The period 1991–2000 has the tightest overall grouping meaning that it is representative across all major river basins (Figure F-2).



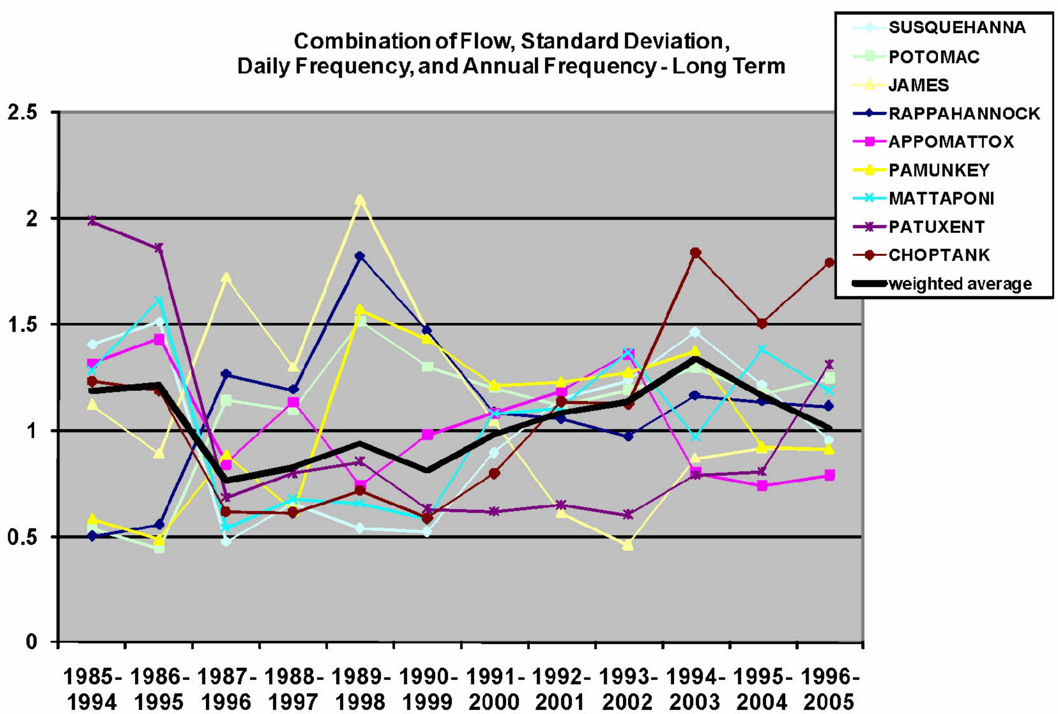


Figure F-2. The combined statistic for the candidate 10-year periods by the nine major river basins for the 30-year flow record (a) and the available long term flow record (b).

The 10-year hydrologic assessment period from 1991 to 2000 was selected by the Water Quality Goal Team for the following reasons:

- It was one of the 10-year periods within the 1985–2005 Chesapeake Bay model simulation period that was closest to an integrated metric of long-term flow.
- Each of the nine major river basins had statistics that were particularly representative of the long-term flow for both the 30-year flow record and available long-term flow record.
- It overlaps several years with the previous 2003 tributary strategy allocation assessment period (1985–1994) facilitating comparisons between the two assessments.
- It incorporates more recent years than previous 2003 assessment period (1985–1994).
- It encompasses the complete decade of 1991–2000, which is a straightforward span of time to communicate to the public,
- It overlaps with the Chesapeake Bay Water Quality Model calibration period (1993–2000), which is important for the accuracy of the model predictions.
- The 10-year period encompasses the 3-year critical period (1993–1995) for the Chesapeake Bay TMDL as explained in Section 6.2.1 and documented in Appendix G.